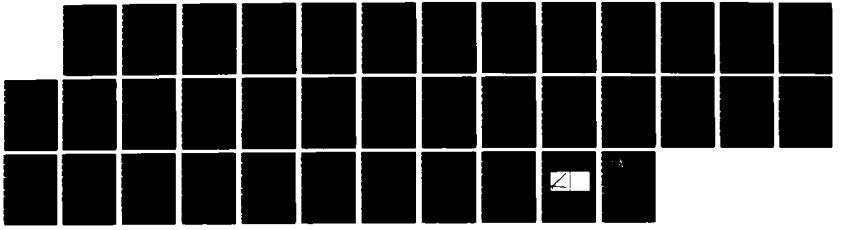
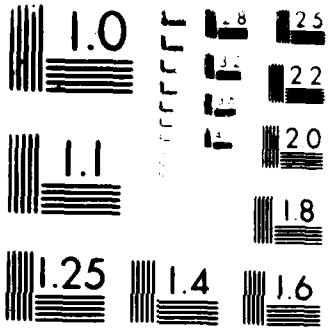
AD-A177 289 RESEARCH IN ELECTRONICS JOINT SERVICES ELECTRONICS PROGRAM(U) UNIVERSITY OF SOUTHERN CALIFORNIA LOS ANGELES SCHOOL OF ENGINEERING W H STEIER 31 DEC 86 1/1

UNCLASSIFIED AFOSR-TR-87-0006 F49620-85-C-0071 F/G 9/5 NL




1.0
1.1
1.25
1.4
1.6
1.8
2.0
2.2
2.5

4 PERFORMING ORGANIZATION REPORT NUMBER(S)

5. MONITORING ORGANIZATION REPORT NUMBER(S)

AFOSR-TR- 87-0006

6a. NAME OF PERFORMING ORGANIZATION	6b. OFFICE SYMBOL (If applicable)	7a. NAME OF MONITORING ORGANIZATION
Univ. of CA		AFOSR/NE

6c. ADDRESS (City, State and ZIP Code)	7b. ADDRESS (City, State and ZIP Code)
School of Engineering University Park LA, CA 90089	Bld 410 Bolling AFB DC 20332

8a. NAME OF FUNDING/SPONSORING ORGANIZATION	8b. OFFICE SYMBOL (If applicable)	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
same as 7b	NE	F49620-85-C-0071

8c. ADDRESS (City, State and ZIP Code)	10. SOURCE OF FUNDING NOS.			
	PROGRAM ELEMENT NO.	PROJECT NO.	TASK NO.	WORK UNIT NO.
same as 7b	61102F	2305	A9	

11. TITLE (Include Security Classification)
Research in Electronics Joint Services Program

12. PERSONAL AUTHOR(S)
Professor Steier William H

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Yr., Mo., Day)	15. PAGE COUNT
Annual	FROM 1-1-86 TO 12-31-86		

16. SUPPLEMENTARY NOTATION

17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB. GR	

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

The modeling of the photoconductive process, when combined with earlier work on diffraction from volume phase gratings, has extended the understanding of the photorefractive recording process and its fundamental limitations. This work has been applied to the Photorefractive Incoherent-to-Coherent Optical Connector.

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT	21. ABSTRACT SECURITY CLASSIFICATION
UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT ☐ DTIC USERS ☐	UUUU

22a. NAME OF RESPONSIBLE INDIVIDUAL	22b. TELEPHONE NUMBER (Include Area Code)	22c. OFFICE SYMBOL
Dr. Gerald Witt	767-4931	NE

AFOSR-TR- 87-0006

JOINT SERVICES ELECTRONICS PROGRAM

RESEARCH IN ELECTRONICS

CONTRACT NO. F49620-85-C-0071

1986/87 ANNUAL REPORT

For the Period 1 January 1986 through 31 December 1986

SUBMITTED TO:

AIR FORCE OFFICE OF SCIENTIFIC RESEARCH
BUILDING 410
BOLLING AIR FORCE BASE, DC 20332

SUBMITTED BY

UNIVERSITY OF SOUTHERN CALIFORNIA
SCHOOL OF ENGINEERING
UNIVERSITY PARK
LOS ANGELES, CALIFORNIA 90089-0483

Joint Services Electronics Program
TABLE OF CONTENTS

UNIVERSITY OF SOUTHERN CALIFORNIA

JOINT SERVICES ELECTRONICS PROGRAM
CONTRACT NO. F49620-85-C-0071

RESEARCH IN ELECTRONICS

DIRECTOR'S OVERVIEW

This report summarizes the progress made under the Joint Services Electronics Program for the period 1 January 1986 through 31 December 1986. It is the second annual progress report on the three-year contract, F49620-85-C-0071. The report covers the thirteen research projects being supported: four in solid state electronics, four in quantum electronics, and five in information electronics.

The report also summarizes the significant accomplishments that have been achieved during this research period.

SIGNIFICANT ACCOMPLISHMENTS

Fundamental Limitations on the Photorefractive Recording Process - Armand R. Tanguay, Jr. - ***Research Unit SS2-3***

The modeling of the photoconductive process, when combined with earlier work on diffraction from volume phase gratings, has extended the understanding of the photorefractive recording process and its fundamental limitations. This work has been applied to the Photorefractive Incoherent-to-Coherent Optical Connector.

New Organic Materials for Rectifying Organic - Semiconductor Interfaces - S.R. Forrest - ***Research Unit SS2-4***

A broad new class of phthalocyanine (Pc) based organic materials has been found to form high rectifying energy barriers when deposited on to inorganic semiconductors. Successful OI contacts have been formed between p-Si and copper Pc.

High T_0 Low Threshold Lasers - E. Garmire - ***Research Unit QE2-1.***

High T_0, low threshold InGaAsP/InP lasers at 3 μm have been successfully grown. These lasers were grown on p-type InP substrates.

SOLID STATE ELECTRONICS

HETEROJUNCTION MATERIALS AND DEVICES EMPLOYING ULTRATHIN LAYERS GROWN BY METALORGANIC CHEMICAL VAPOR DEPOSITION (MOCVD)

Research Unit: SS2-1
P.D. Dapkus

For the Period: 1 January 1986 through 31 December 1986

Progress

The reconfiguration of our MOCVD reactor to grow ultrathin layers is now complete. Layers as thin as 20Å are routinely grown in the AlGaAs/GaAs materials system. The doping of n- and p-type layers throughout the whole system is also complete. We have used diethylzinc as the p-type dopant and have been able to grow layers that range in doping from $5x10^{16}$ cm^{-3} to greater than $1x10^{19}$ cm^{-3}. A major difficulty with this dopant is the limited dynamic range available at any growth temperature. The dynamic range is limited by the sticking coefficient of Zn in the material and the flow controller ranges. At present only an order of magnitude dynamic range is controllable at most growth temperatures. A modification of the system to include multiple sources or multiple mass flow controllers is being contemplated. A similar though less severe problem is experienced in the n-type doping of these materials. We are currently using a commercially supplied Si_2H_6 doping source. Unfortunately, the temperature behavior of the doping suggests that the source is SiH_4. Decomposition of Si_2H_6 in the source bottle is promoted by the residual water vapor in the source. In spite of these difficulties doping over the range $1x10^{16}$ to $1x10^{19}$ cm^{-3} is achievable in the appropriate temperature ranges. With these sources calibrated we are able to concentrate on the technical challenges in growing two of the more interesting electronic devices that can be fabricated by MOCVD - the selectively doped heterojunction FET and the heterojunction bipolar transistor (HBT).

We have begun to fabricate selectively doped heterojunctions and to characterize their electrical characteristics with capacitance measurements. Normal and inverted structures are being fabricated in a configuration that allows the determination of the interface charge at the heterojunction and the conduction and valence band energy offsets. The carrier concentration profile of an inverted heterojunction structure is shown in Fig.1. This sample shows an interface charge density, $\sigma \approx 3x10^{10}$ cm^{-3}. We are studying the effect of growth conditions and doping source purity on the measured interface charge density. When sufficiently low interface charge densities are achieved we will concentrate on the fabrication of transport samples to optimize the low

temperature mobilities of the two dimensional electron gas and on the fabrication SDHT devices.

The acquisition of high purity Ga source materials has allowed us to fabricate materials with background carrier concentrations as low as 3 $x10^{14}$ cm^{-3}. The highest mobility we have achieved is 8 x 10^4 cm^2/V-sec. We will attempt to use triethylgallium and triethylaluminum rather than the methyl compounds to improve the C incorporation and improve the purity of the AlGaAs and GaAs. Recent work at GTE laboratories has shown that mobilities in GaAs as high as 2 X 10^5 cm^2/ V-sec are possible with ethyl compounds utilizing low pressure growth techniques.

Modeling of HBT structures including structural and fabrication enhancements has been competed. We have developed a PC based Modeling algorithm that employs a lumped circuit model of the transistor in which the circuit element values are based on those calculated from the physical structure and materials properties employed in the structure. The materials structure parameters are used in a physical simulator to estimate the gain in the structure. An enhancement of the simulator has been developed that allows us to calculate the transit time contributions of the various portions of the transistor these are compare to the values calculated from traditional formulae. Fig 2 shows the output of this simulator showing the distribution of the transit time of a Pnp transistor. The plot shows both the electron and hole transit time. Note that the transit ti,e in this device is dominated by the time to cross the neutral base region. SPICE simulations of the transistor have also been carried out to compare with the lumped model and a model that converges to the results of SPICE and the physical simulator in the appropriate limits has been developed. With this model we have considered the performance of microwave and switching transistors in the Npn and Pnp configuration with various fabrication and structural enhancements. The results of these simulations suggest that the major limiting factor in the high speed performance of HBT's is the RC time constants associated with the various layers and junctions. Pnp transistors can be designed that approach the speed of the fastest Npn designs. Little improvement in the speed performance can be achieved by incorporating graded base layers since the performance is not limited by the base transit time. The major improvement can be had by introducing a self-aligned structure and by reducing extrinsic capacitances in the device design.

We have begun to fabricate Pnp transistor structures to verify the gain characteristics. The early structures will not be constructed with geometries that are conducive to high speed operation, but rather will concentrate on the achievement of high gain.

List of Publications

1. D. A. Sunderland and P. D. Dapkus, IEEE Electron Device Lett., **EDL6,** 648 (1985).

2. S. P. Den Baars, B. Y Maa, P. D. Dapkus, A. D. Danner and H. C. Lee, J. Crystal Growth, 77, 188 (1986).

3. D. A. Sunderland and P. D. Dapkus, IEEE Trans. Electron Dev. (Feb. 1987).

4. H.C. Lee, A. Hariz, P. D. Dapkus, A. Kost, M. Kawase, and E. Garmire, submitted for publication in Appl. Phys. Lett.

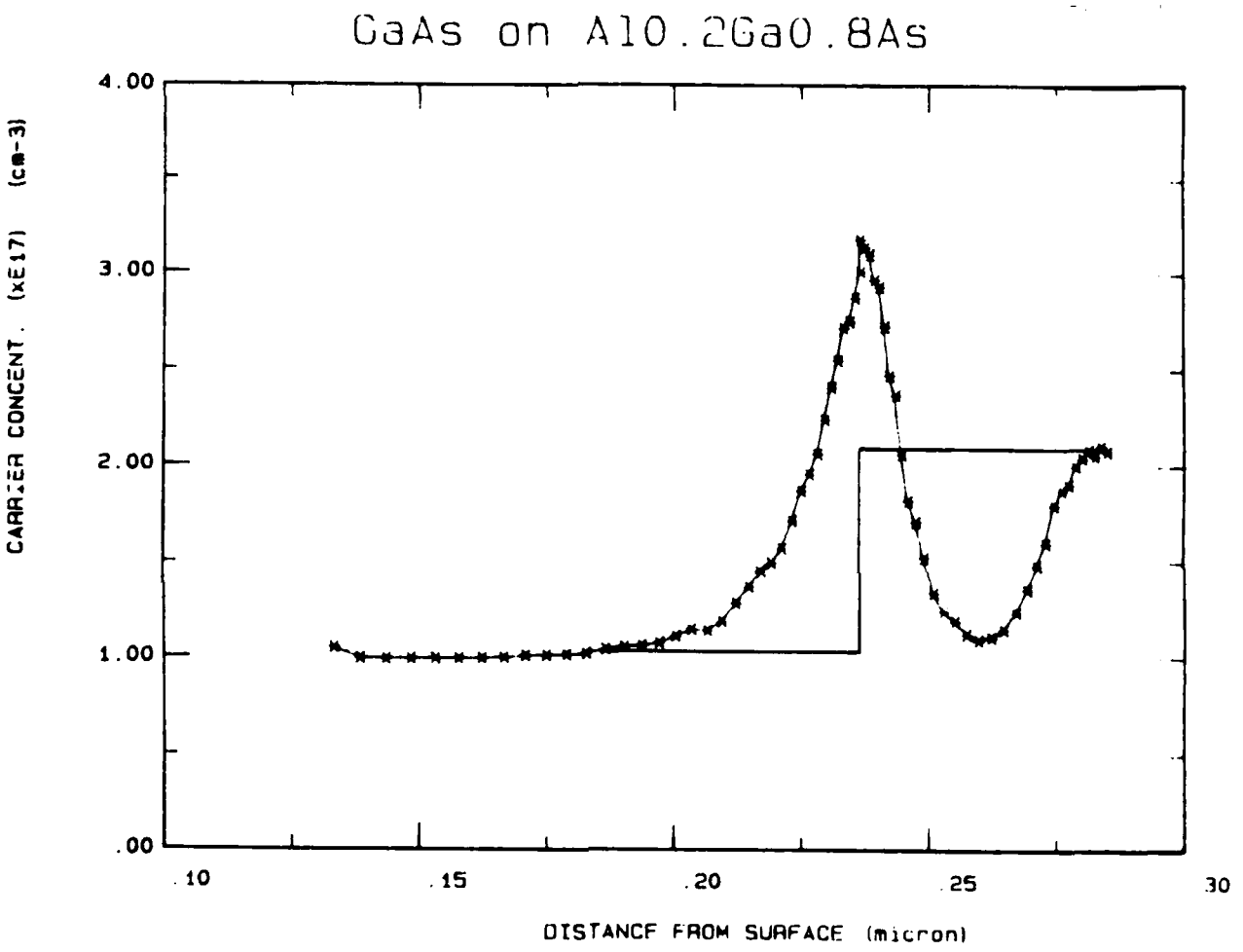
List of Presentations

1. D. A Sunderland and P. D. Dapkus, Talk presented at 1986 Device Research Conference, Amherst, MA.

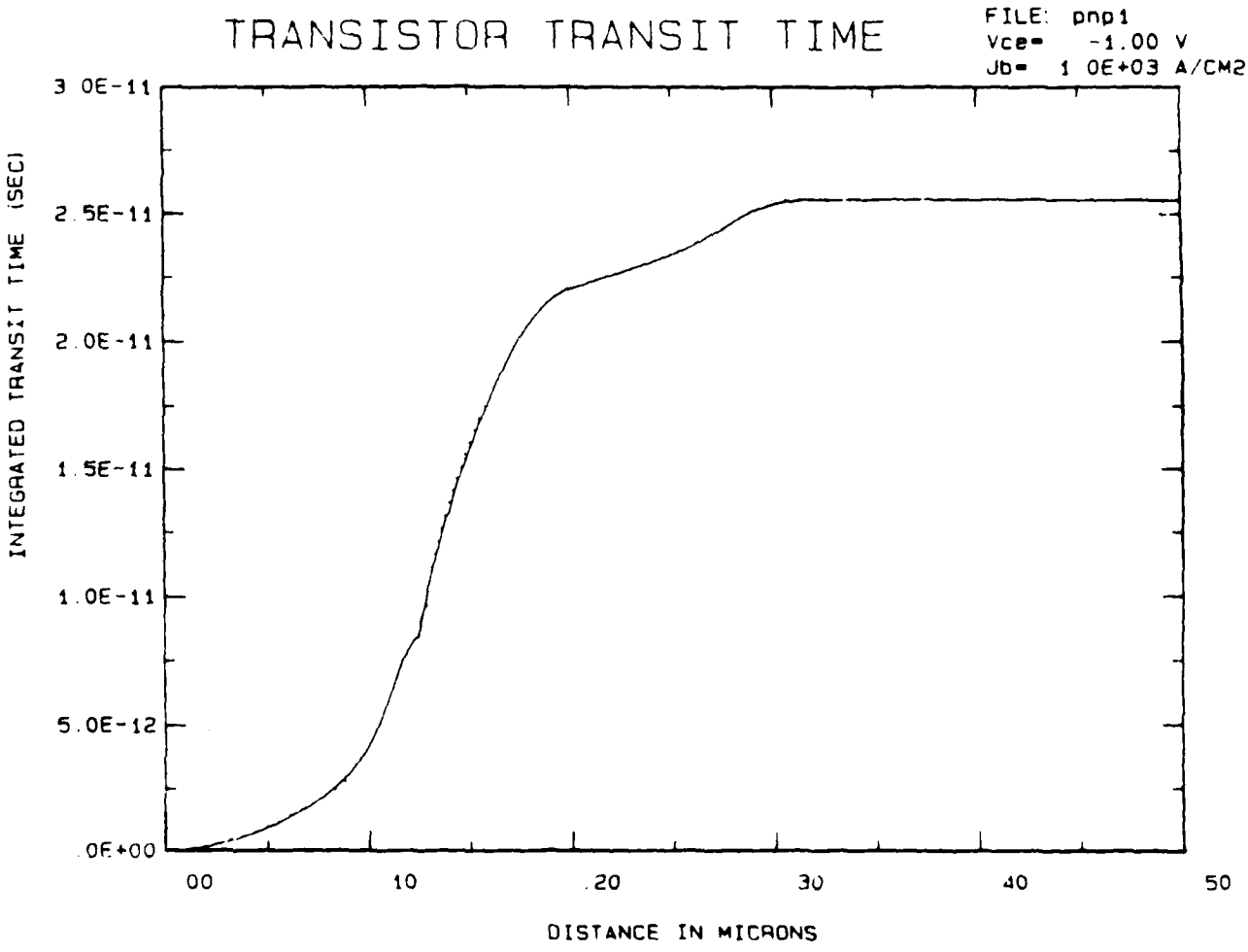
2. S. P. Den Baars, B. Y. Maa, P. D. Dapkus, A. D. Danner, and H. C. Lee, Talk presented at ICMOVPEIII , April 1986, Los Angeles, CA.

3. H.C. Lee, A. Hariz, P. D. Dapkus, A. Kost, M. Kawase, and E. Garmire, Talk accepted for presentation at the Topical Meeting on Photonic Switching, Lake Tahoe, March, 1987.

SS2-1 Figure 1



SS2-1 Figure 2



SOME INVESTIGATIONS OF THE KINETICS AND MECHANISM OF MOLECULAR BEAM EPITAXIAL GROWTH

Research Unit: SS2-2
A. MADHUKAR

For the Period: 1 January 1986 through 31 December 1986

Research Objective

The task proposed under work unit SS4-2 defined its objective to be (a) systematic growth of GaAs/$Al_xGa_{1-x}As$(100) quantum well structures grown under condition suggested by our earlier reflection-high-energy-electron-diffraction (RHEED) intensity dynamics studies to be optimized and (b) to continue exploring influence of growth conditions dependent surface kinetic effects via examination of RHEED intensity behavior. The following describes the progress towards these objectives during this reporting period.

Progress

(a) During this period, a major step forward was the identification by us of the presence of irreversible behavior of the static and steady state RHEED specular beam intensity and its implications for the existence of metastable surface step density which is smoother than the stable static surface behavior. This is shown in fig. 1.

(b) The above noted observation of an intrinsic behavior of the surfaces, for the first time, allows reproducibility of growth conditions from day to day on the same MBE machine and from one machine to another, independent of the uncertainties in the customary reliance on thermocouples, infrared pyrometers and ion gauges for determination of substrate temperature (T_S) and group V pressure (P_{As4}), respectively.

(c) A series of single quantum well structures with well width varying between 3 monolayers (ML) and 40 ML were grown under RHEED determined identical growth conditions. Equally significant, the growth condition chosen corresponds to the optimal conditions - the metastable surface noted under (a) above for growth with the new approach of growth interruption, and the maxima in the steady state intensity in the (T_S, P_{As4}) two dimensional growth parameter space at the chosen growth rate for the customary practice of growth without interruption.

Under separate (AFOSR) sponsorship the photoluminescence (PL) and PL excitation (PLE) behavior of these samples was systematically examined. The observed

PL linewidth Γ of the first electron to heavy hole free-exciton recombination, as a function of the well width (d_w), for wells grown without interruption is shown in fig. 2. The nearly $\Gamma \sim d_w^{-1}$ behavior demonstrated for the first time invalidates the customarily used notion and model of fluctuations in the well width being the dominant scattering mechanism in high quality samples. Rather, it is the fluctuation in the interfacial chemical composition giving rise to fluctuations in the band-edge discontinuity on the scale of the exciton size and a shorter-ranged alloy disorder scattering which control the PL linewidth. The solid curves in fig. 2 show the behavior of Γ calculated in a theory based upon this view of the nature of high quality interfaces. We parenthetically note that the absolute values of Γ seen in fig. 2 are amongst the narrowest line widths ever reported for quantum wells in this thickness regime and testify to the value of RHEED studies in arriving at optimized growth conditions.

List of Publications

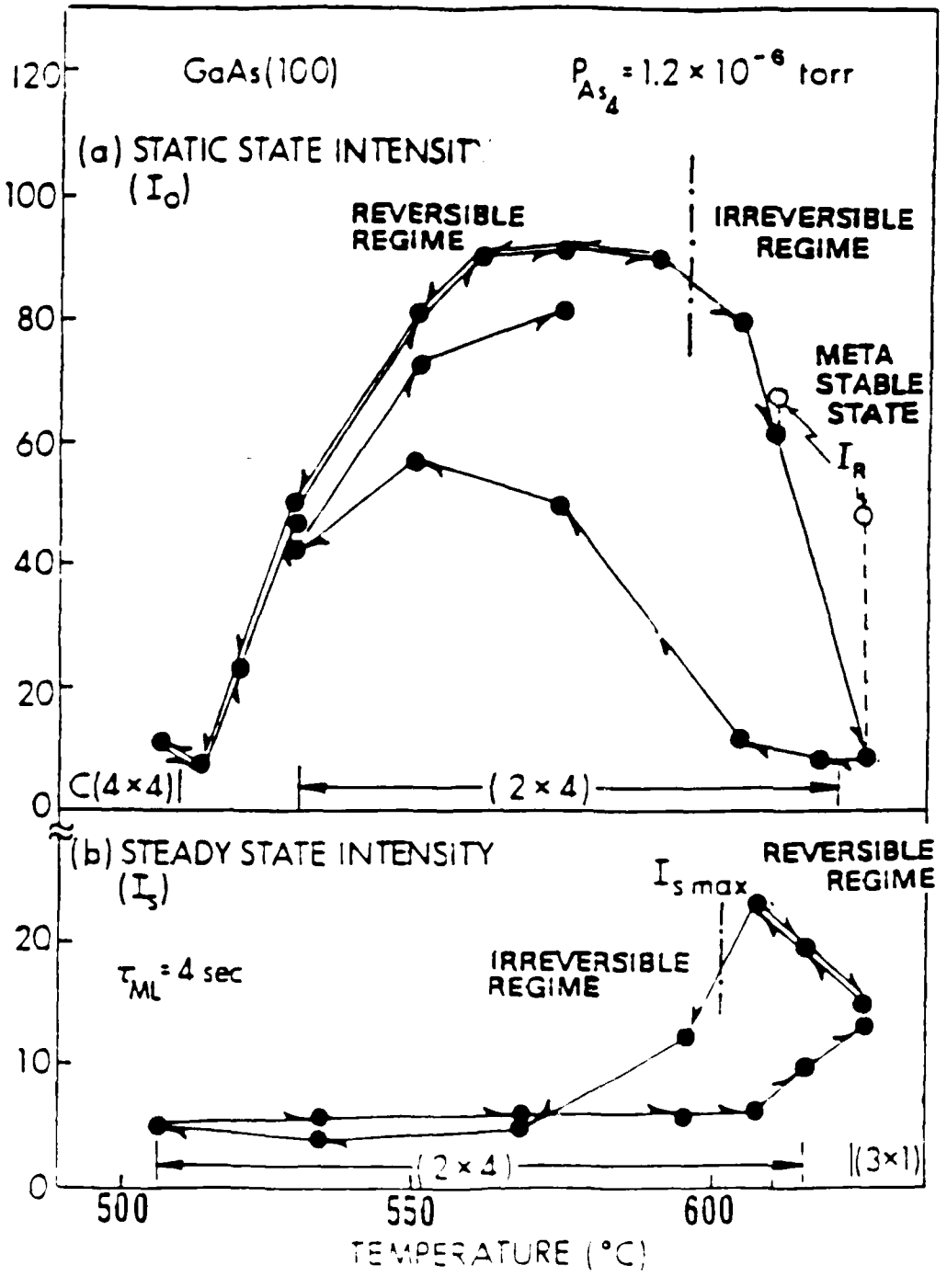
1. P. Chen, J.Y. Kim, A. Madhukar and N.M. Cho, Jour. Vac. Sc. Tech. **B4**,890 (1986).

List of Presentations

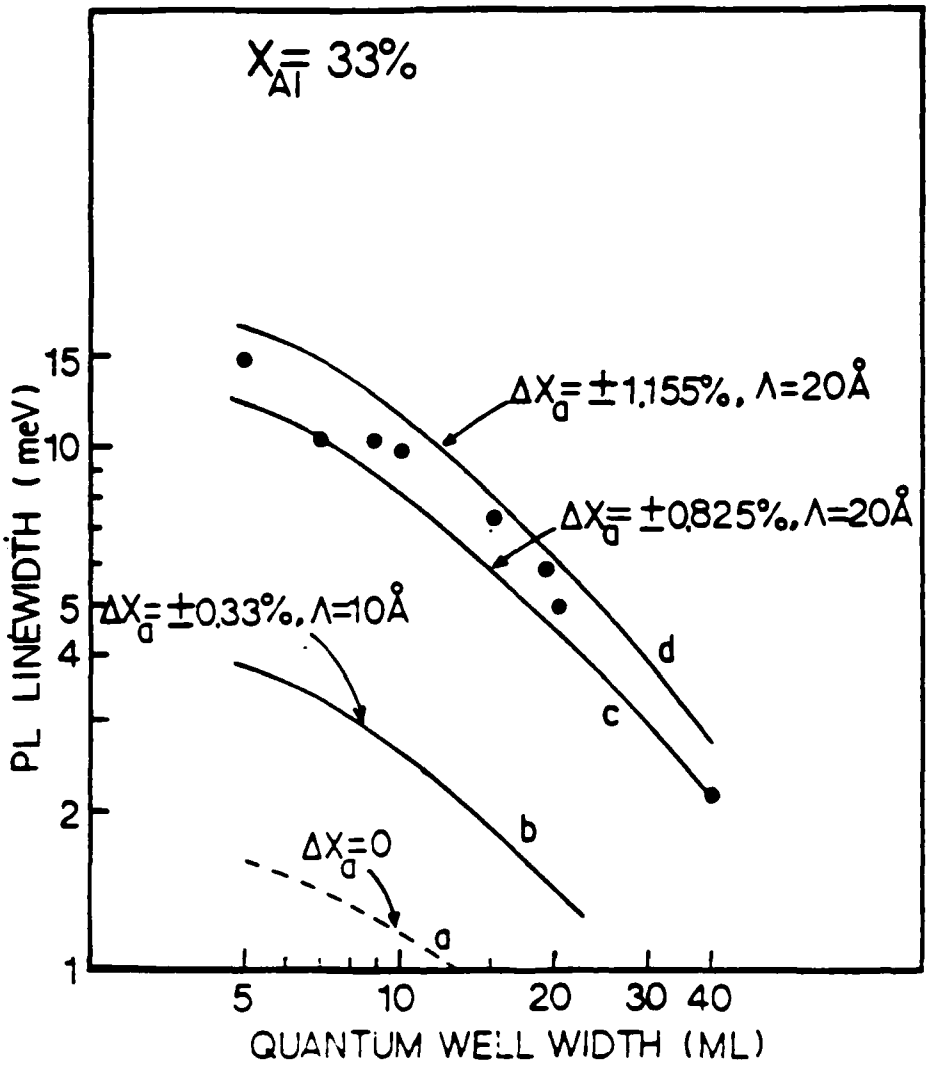
2. F. Voillot, J.Y. Kim, W.C. Tang, A. Madhukar and P. Chen, paper presented at 2nd International Conference on Superlattices, Goteborg, Sweden (Aug. 11-15, 1986). Proceedings in Superlattices and Microstructures (In Press).

3. J.Y. Kim, F. Voillot, P. Chen, A. Madhukar and N.M. Cho, paper presented at 27th Electronic Materials Conference, Amherst, Mass. (June 24-26, 1986); Jour. Elec. Materials, **15**, 317 (1986).

SS2-2 Figure 1



SS2-2 Figure 2



ELECTROOPTIC MATERIALS FOR OPTICAL PROCESSING AND COMPUTING DEVICES

Armand R. Tanguay, Jr.
Research Unit SS2-3

Progress

During the most recent contract period, significant progress has been achieved in the modeling of photoconductive processes in media such as bismuth silicon oxide (BSO). Such modeling, when combined with studies of the polarization properties of diffraction from photorefractive volume phase gratings (as were developed and reported during the previous contract period) significantly extends our understanding of the photorefractive recording process and its fundamental limitations.

Analytical modeling of the photoconductive processes has emphasized a perturbation series study of the photorefractive recording of multiple image structures. The immediate application of this work has been for a more detailed understanding of the Photorefractive Incoherent-To- Coherent Optical Converter (PICOC), a novel two dimensional spatial light modulator that has been explored under this contract. However, the resulting perturbation series model applies to a much broader range of devices. Details of the analysis and its application to PICOC performance is provided in JSEP Pub. 1.

One immediate consequence of this modeling has been the observation of an inherent inefficiency in the photorecording process when a high bias electric field is applied to heighten the photoconductive sensitivity. This inefficiency applies to broad classes of photorefractive recording, not just to PICOC. The inefficiency pertains to the placement of photoinduced charges to create a prescribed charge profile. One interesting technique to minimize this inefficiency is to use one form of the PICOC process whereby a single spatial frequency grating is recorded with high bias fields, and then selectively erased by the image-bearing light beam with no bias field applied. This concept will be further explored in the following contract period.

The analytical model of the photoconductive mechanism is inherently limited in its accuracy; more accurate models require numerical techniques. Such a numerical model has been developed during the contract period, and applied to a study of the relative merits of "running grating" and "stationary grating" photorefractive recording techniques. The "running grating" technique appears to be most effective for low modulation depths, i.e., for weak information signals.

The previously developed models of the optical polarization properties of light diffraction from photorefractive gratings (JSEP Pubs. 2 and 3), when combined with the photoconductive models, enable a more accurate description of diffraction efficiency for running gratings in BSO. Because of the presence of optical activity, the coupling efficiency degrades, typically by as much as a factor of two. This partially explains why electrooptic coefficients observed in photorefractive measurements have been significantly lower than those measured by other techniques. Details have been given in JSEP Conf. 1.

List of Publications:

1. J. Yu, D. Psaltis, A. Marrakchi, A. R. Tanguay, Jr., and R. V. Johnson, "The Photorefractive Incoherent-To-Coherent Optical Converter," in Photorefractive Materials and Applications, J. P. Huignard and P. Gunter, Eds., Springer-Verlag, New York (in press).

2. A. Marrakchi, R. V. Johnson, and A. R. Tanguay, Jr., "Polarization Properties of Photorefractive Diffraction in Electrooptic and Optically Active Sillenite Crystals (Bragg Regime)," J. Opt. Soc. Am. **B2**, 321 (1986).

3. R. V. Johnson and A. R. Tanguay, Jr., "Optical Beam Propagation Method for Birefringent Phase Grating Diffraction," Opt. Eng. **25**, 235-249 (1986). (Invited manuscript in Special Issue on Materials and Devices for Optical Information Processing.)

List of Presentations

1. A. Marrakchi, R. V. Johnson, and A. R. Tanguay, Jr., "Polarization Properties of Two-Beam Coupling With Running Gratings in BSO," 1986 Annual Meeting of the Optical Society of America, Seattle, WA, Oct. 1986.

ELECTRONIC SURFACE ANALYSIS USING NON-DESTRUCTIVE ORGANIC-ON-INORGANIC SEMICONDUCTOR CONTACTS

S.R. Forrest
Research Unit SS2-4

For the period 1 January 1986 through 31 December 1986

Progress

The work included in this new unit began in April, 1986. During the time period between April and December, several important new results were obtained which should lead to a deeper understanding of organic-on-inorganic (OI) semiconductor contact barriers. During the first period of this work, the OI deposition process consisting of a high vacuum ($P < 10^{-8}$ Torr obtainable) deposition system was brought into operation. These are the highest vacuum conditions yet achieved in the fabrication of OI diodes, and will be instrumental in the coming year in determining the effects of exposure to environmental conditions on the size of the OI interface energy barrier and density of interface states. In addition, a two-fold organic purification system was constructed whereby the crystalline organic material is first cleaned by a 6-day solvent extraction method, followed by a 4 to 6 day gradient sublimation process. Via these means, the highest purity materials can be obtained for future work on the fundamental nature of the OI interface.

The most interesting discovery of the last six months is that a broad new class of organic materials have been found to form high rectifying energy barriers when deposited onto inorganic semiconductors. In past work, only perylenetetracarboxylic dianhydride (PTCDA), naphthalenetetracarboxylic dianhydride (NTCDA) and related compounds were found to exhibit the effects of both space charge injection as well as formation of an appreciable energy barrier to room temperature electron transport at the OI interface. Heretofore, attempts at observing the same effects in the phthalocyanine-based materials have not met with success. Nevertheless, the phthalocyanines (Pc) have excellent space-charge transport properties, and form extensive crystalline stacks which suggest that they should also exhibit OI-rectification properties. In addition, the Pc's can be made to exhibit a broad range of optical and electronic properties simply by substituting various metal ligand atoms in the center of the molecule. For these reasons, branching out into the Pc's is of central importance to both our understanding and our use of the OI interface. This year we were successful in forming OI contacts between p-Si and copper Pc (CuPc). The barrier height measured was 0.67 eV (c.f. 0.75 eV for PTCDA/p-Si contacts). The variation of barrier height with organic composition suggests that the mechanism for barrier formation is an intrinsic property of the organic thin film. An additional observation is that the diode n-value extracted from the

forward-biased I-V characteristics is nearly double that of the PTCDA/p-Si value of n=1.5. From earlier analysis of the interpretation of the OI n-value, the discrepancy indicates the existence of a considerably increased surface state density for the CuPc contact, which is probably also responsible for the lower energy barrier. This observation is corroborated by distortion observed in the C-V data obtained for the CuPc diode as opposed to the PTCDA device (see the figure below).

Systematic analysis of these observations are now underway. Indeed, we expect that a detailed experimental probing of the comparison of OI interfacial properties observed for PTCDA, NTCDA and CuPc will greatly clarify the important factors involved in OI energy barrier formation. There is a considerable body of knowledge which has thus far been accumulated on the crystalline structure and transport mechanisms of these three materials. These protypes therefore form the basis of our approach to understanding OI heterojunctions.

Progress has also been made on several other aspects of this project. For example, in past work it has been shown that analysis of the quasi-static C-V and G-V characteristics of the OI diode gives quantitative information about the density and distribution of defect states residing at the OI interface. This so-called semiconducting organic-on-inorganic surface analysis spectroscopic (SOISAS) technique, however, has several shortcomings including dependence to bias sweep rate and low sensitivity. We have recently made progress in developing truly a.c. means of implementing SOISAS. Initial computer simulations indicate a greatly enhanced sensitivity to the presence of deep levels. Still to be solved is a means of simplifying the analysis procedure such that the data can be interpreted without application of unnecessarily complex computer data reduction algorithms. Finally, in anticipation of future work in this exciting field, we have designed an apparatus to be installed in our high vacuum system which allows for the complete fabrication of the two level OI diode, as well as electronic and optical probing without breaking vacuum at any point in the measurement or fabrication sequence. This capability is essential if we are to determine the effects of environmental factors (such as oxygen and water adsorption onto the inorganic semiconductor surface) on the formation of the OI energy barrier. Additionally, this apparatus can be used to determine the utility of the OI barrier as a contaminant gas detector, etc. The equipment necessary to implement these experiments is currently on order, and we expect to begin assembly by early January, 1987.

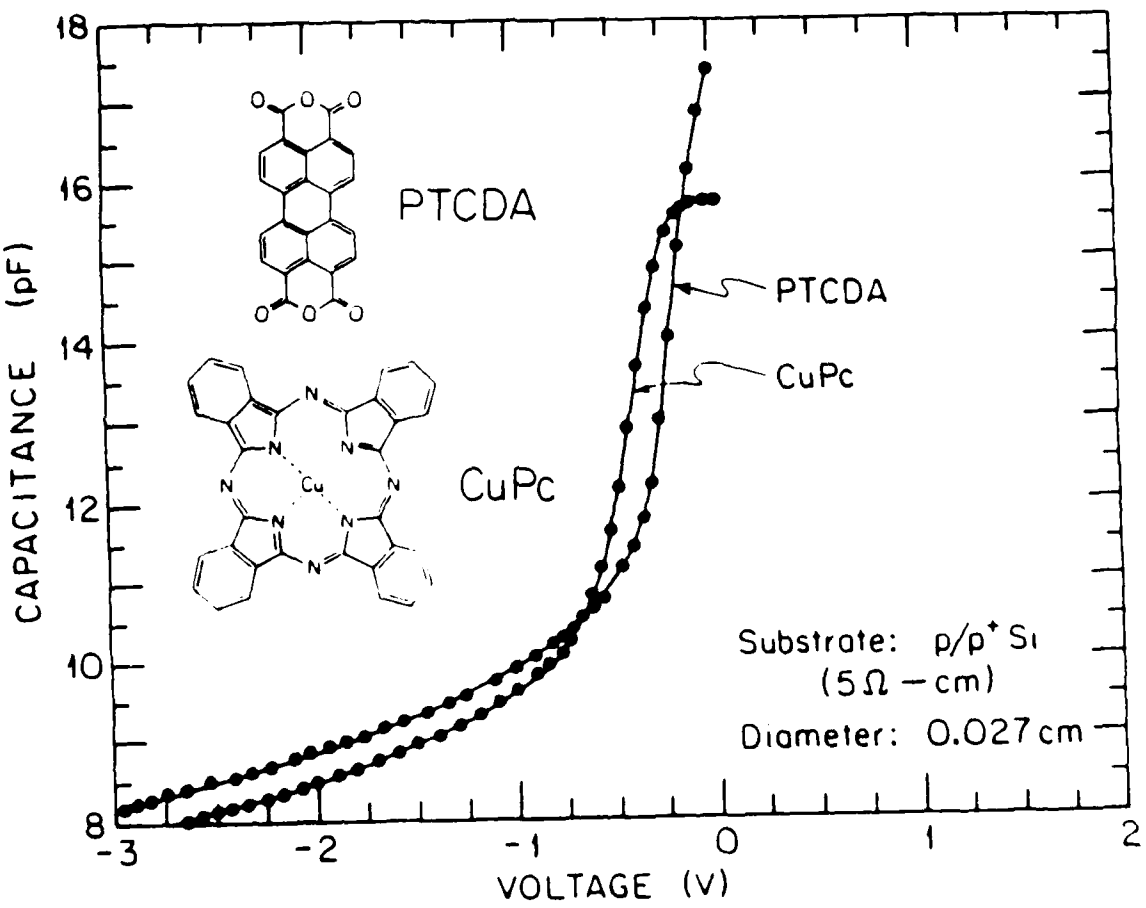
List of Publications

1. S.R. Forrest, M. L. Kaplan, and P. H. Schmidt, "Organic thin films for semiconductor wafer diagnostics," invited chapter submitted to the Annual Reviews of Materials Science, vol. 17, 1987, Annual Reviews, Inc.

List of Presentations

1. S.R. Forrest, "Semiconductor contacts using organic thin films," invited paper at Physics and Chemistry of Semiconductor Interfaces Meeting, Salt Lake City, January 27-29, 1987.

SS2-4 Figure 1



QUANTUM ELECTRONICS

TOWARD ROOM TEMPERATURE LASERS IN THE 3μm WAVELENGTH REGION

E. Garmire
Research Unit QE2-1

For the period 1 January 1986 through 31 December 1986

Progress

First, high T_O, low threshold lasers predicted and developed in the previous JSEP phase were finally successfully grown and characterized, using a new p-DCC geometry. They fully lived up to their predictions. We published an Applied Physics Letters article, Tom Hasenberg completed his thesis and final manuscripts were prepared describing the results. A patent application was filed.

Second, new students are taking data on the high temperature operation of the p-DCC lasers, which should lead to another paper when finished.

Third, the new students have done a few practice LPE runs. However, the equipment went down and replacement parts have taken a long time in arriving. As a result, no growths of 3 μm material were completed. The LPE system should be operational by January.

List of Publications

1. T. C. Hasenberg and E. Garmire, "Low Threshold High T_O InGaAsP/InP 1.3μm Lasers grown on p-type InP Substrates", Appl. Phys. Lett., **49**, 400 (1986).

2. T.C. Hasenberg and E. Garmire "An Improved Au/Be Contact to p-type InP", Journal of Applied Physics, September, 1986.

3. T. C. Hasenberg,"Low threshold, High T_O InGaAsP/InP 1.3 μm Lasers Grown on p-type InP Substrates with a three-Melt Technique" Ph.D. Dissertation in Materials Science, May 1986.

4. T. C. Hasenberg and E. Garmire "Characteristics of InGaAsP/InP p-DCC lasers grown by the Three-Melt Technique" Submitted to Journal of Quantum Electronics, November 1986

5. T.C. Hasenberg and E. Garmire, "Heterostructure Laser and Related Method": Patent Applied for, June, 1986.

List of Presentations

1. T.C. Hasenberg and E. Garmire, "Low Threshold, High To GaInAsP/InP Lasers" , CLEO '86, post-deadline paper.

2. T.C. Hasenberg and Garmire, "Low Threshold, High To 1.3 μm Lasers Grown by a Three-Melt Technique" , Device Research Conference June, 1986.

3. T.C. Hasenberg and E. Garmire, "Performance Characteristics of P-DCC GaInAsP Lasers", International Semiconductor Laser Conference, October , 1986.

A SPECTROSCOPIC STUDY OF BASIC PROCESSES IN ELECTRICALLY EXCITED MATERIALS

Martin A. Gundersen
Research Unit QE2-2

Report Period: 1 January 1986 through 31 December 1986

Progress

New spectroscopic methods have been developed and applied to the study of high power gas phase switches. These methods now provide quantitative information about the populations of excited states in a high current discharge, data for time dependent microscopic models of high power switches, and other information.

Results include:

- Time-resolved absolute measurements of Balmer populations in atomic hydrogen using laser-induced fluorescence.

- Application of laser-induced fluorescence to the measurement of Stark broadening in hydrogen, thus providing time-resolved electron densities, and overcoming several deficiencies associated with other methods.

- Development of a time dependent model of the recovery phase in a hydrogen thyratron.

- Experimental data along with a model showing three-body recombination to be important in high power thyratron recovery, thus pinpointing the role of this recovery, thus pinpointing the role of this recovery mechanism for the first time.

The spectroscopic studies effort is having an impact on the development of high power devices in the following way. The understanding of fundamental physical processes is leading to an understanding of high power device limitation. Further, the models and data can be applied to the development of new devices. Thus, it should be possible to develop predictive models of devices that are based on new ideas. Examples would include most devices involving electron impact ionization, such as glow discharge switches, and optogalvanic-effect switches, and the BLT.

The BLT (back-light thyratron) is a development that is related to and is partially an outgrowth of this research effort. It is a new switch that holds promise for replacing thyratrons in some applications. The BLT has operated at 35 kV standoff voltage and 7000 A peak current. It's advantages include glow discharge, gridless operation, cold hollow cathode, high peak current, high current rate of rise. It is triggered by an unfocused light source.

List of Publications

1. "Summary of the workshop for research issues in power conditioning," M.A. Gundersen, editor, University of Southern California (1986).

2. "A semi-empirical formalism for the calculation of deep level wavefunctions in k space," H-H. Dai, M.A. Gundersen, and C.W. Myles, Phys. Rev. B. **33**, 8234 (1986).

3. "Measurement of excited-state densities during high-current operation of a hydrogen thyratron using laser-induced fluorescence," D.A. Erwin and M.A. Gundersen, Appl. Phys. Lett. **48**, 1773 (1986).

4. "Determination of electric field and electron temperature in the positive column of a high-power hydrogen thyratron from non-intrusive measurements," D.A. Erwin, J.A. Kunc and M.A. Gundersen, Appl. Phys. Lett. **48**, 1727 (1986).

5. "A low pressure, light initiated, glow discharge switch for high power applications," G.F. Kirkman and M.A. Gundersen, Appl. Phys. Lett. **49**, 494 (1986).

6. "Resonant behavior in the luminescence processes of N-doped GaP," H.H. Dai, M.A. Gundersen, C.W. Myles, and P.G. Snyder, in preparation.

List of Presentations

7. M.A. Gundersen, J.A. Kunc, D. Erwin, and C. Braun, "Fundamental processes in high current glow discharge switches, "Proceedings Elektronenröhren und Vakuumelectronic, NTG-Fachberichte **95**, 94 (1986).

8. M.A. Gundersen, R. DeWitt, A.K. Hyder, C.R. Jones, J.A. Kunc, M.J. Kushner, E.P. Muntz, G. Schaefer, and P.F. Williams,"Research issues in power conditioning," Proceedings 1986 Seventeenth Power Modulator Symposium, Seattle, WA, June 23-25, 1986.

9. C.G. Braun, D.A. Erwin, G.F. Kirkman, and M.A. Gundersen, "A linear thyratron for developmental research," Proceedings 1986 Seventeenth Power Modulator Symposium, Seattle, WA, June 23-25, 1986.

OPTICAL SWITCHING

William H. Steier
Research Unit QE 2-3

For the period 1 January 1986 through 31 December 1986

Progress

Photorefractive materials are a very promising nonlinear medium for use in optical switching, phase conjugation and optical information processing. The high resistivity III-V semiconductors, particularly GaAs, are of particular interest because of their fast photorefractive response and their possible use in the infrared at diode laser wavelengths.

Two wave mixing in photorefractive materials can be used for optical switching, optical gain, and is a convenient method for measuring photorefractive material parameters. We have completed a series of experiments on GaAs:Cr at 1.06 μwhich measured the two wave gain as a function of grating wavelength and applied D.C. electric fields. The grating formation time was also measured as a function of applied field and laser intensity. The "moving grating" technique was also investigated to further enhance the gain when applied fields are used.

These measurements were compared to theory and found to agree reasonably well when the correct ratio of electronic recombination coefficient to electron mobility was assumed. The value of this ratio was confirmed in work supported by other contracts which measured the gain using r.f. electric fields.

The largest gains (~ 1.0 cm^{-1}) were observed with a voltage of 4.0 kV across the sample and the grating moving at optimum velocity. At an intensity of 35 m W/cm^2, a grating formation time of 1.5 msec was measured. The formation time was found to be inversely proportional to the intensity so that a formation time of 1.0 μsec requires ~50 W/cm^2. With applied fields, the grating wavelength for maximum gain is 2-3 μ and the gain at larger wavelengths (8-10 μ is an order of larger than the gain with no applied field.

Using these results, the potential for GaAs in several different optical switching configurations can be determined.

List of Publications

1. G. Albanese, J. Kumar, and W. H. Steier, "Investigation of the photorefractive behavior of chrome-doped GaAs by using two-beam coupling," Optics Lett., **11**, 650 (1986).

2. J. Kumar, G. Albanese, W.H. Steier, and M. Ziari, "Enhanced two-beam mixing gain in photorefractive GaAs using alternating electric fields," to be published Optics Lett., February, 1987.

3. J. Kumar, G. Albanese, and W.H. Steier, "Photorefractive two -beam coupling with applied radio frequency fields: Theory and experiments." Submitted to JOSA B.

4. J. Kumar, G. Albanese, and W.H. Steier, "Measurement of two-wave mixing gain in GaAs with an applied field and a moving grating" in preparation.

List of Presentations

1. G. Albanese, J. Kumar, and W.H. Steier, "Investigation of the photorefractive behavior of chrome-doped GaAs using two-beam coupling, "Optical Society of America, Seattle, WA, October, 1986.

2. J. Kumar, G. Albanese, W.H. Steier, "Photorefractive two-beam coupling in GaAs:Cr with applied r.f. fields and moving grating," submitted to CLEO '87, Baltimore, MD.

SELF-PUMPED OPTICAL PHASE-CONJUGATING LASER RESONATOR CAVITIES

Jack Feinberg

Research Unit QE2-4

Report Period: 1 January 1986 through 31 December 1986

PROGRESS

1) We demonstrated that two separate argon-ion lasers can be locked together using optical phase conjugation. The technique uses four-wave mixing in a photorefractive crystal of barium titanate, and can be extended to more than two lasers. The barium titanate crystal is used in its "self-pumped" mode to optimize the gain of the system. The technique takes advantage of the slow response time t (with low-power illumination) of barium titanate to keep the lasers locked to within a frequency of 1/ t. The two argon-ion lasers were phase-locked to much less than 1Hz for an indefinite time. The extension of this technique to locking together semiconductor lasers will depend on increasing the response of the nonlinear material in the infrared region of the spectrum, and can be accomplished by cooling the crystal close to its transition temperature at 10∞C.

The results of this work were published in Applied Physics Letters.

2) We published a lengthy study on the origin of the photorefractive charge carriers in barium titanate. Our experiments show that oxygen vacancies play an important role in determining the effective density of charge carriers in barium titanate. These vacancies may form complexes with iron impurities to provide the donor and acceptor sites required for photorefractive activity. Understanding the source of the charge carriers is essential for further experiments to alter the nonlinear optical characteristics of this material.

This paper was published in the Journal of the Optical Society of America B.

3) We remeasured the Pockels and piezoelectric coefficients of barium titanate. Accurate values of the Pockels coefficients are necessary for choosing between competing models for the photorefractive effect, and, in particular, for determining the magnitude of the hole and electron densities in these crystals. We found that previous measurements by others gave significantly smaller values for the Pockels coefficients because they ignored the piezoelectric effect in their measurement. Our results imply

that there is more competition than previously suspected between holes and electrons in barium titanate.

This manuscript is in preparation.

4) We invented a new device: a phase conjugator that can change a high-order, distorted laser mode into a low-order, undistorted mode. The device uses a "ring" self-pumped phase conjugator based on a barium titanate crystal, which normally generates the phase-conjugate replica of an input beam. However, we found that by placing a Faraday cell in the ring of the conjugator, the device can be made to produce a different mode, one which is no longer the phase-conjugate mode. The Faraday cell breaks the time-reversal symmetry of the ring, and makes the optical path length different for light propagating in different directions around the ring. The barium titanate crystal compensates for for the asymmetry by choosing a different output mode that has a slightly different propagation constant. By varying the asymmetry caused by the Faraday cell, the shape of the output mode can be reproducibly controlled.

A 16mm movie showing these effects was made by the principal investigator. This results of this research have been submitted to Optics Letters.

List of Publications

1. J. Feinberg and G.D. Bacher, "Phase-locking lasers with phase conjugation," Appl. Phys. Lett. 48, 570 (1986).

2. S. Ducharme and J. Feinberg, "Altering the photorefractive properties of $BaTiO_3$ by reduction and oxidation at 650∞C," J. Opt. Soc. Amer. B3, 283 (1986).

3. J.P. Jiang and J. Feinberg, "Dancing modes: breaking the time-reversal symmetry of a self-pumped phase conjugator," submitted in November to Optics Letters.

List of Presentations

1. Invited paper at SPIE meeting on Practical Holography, "Phase conjugation and real-time holography," Los Angeles, California, January 1986.

2. NSF Workshop on Nonlinear Materials, Annapolis, Maryland, April 1986.

3. Invited paper at CLEO IQEC, "Phase conjugation in photorefractive materials," San Francisco, California, June 1986

4. Contributed paper at CLEO IQEC, "Photorefractive properties of strontium barium niobate," San Francisco, California, June 1986.

5. Series of invited talks at the Conference on Electrooptic and Photorefractive Materials, Erice, Italy, July 1986.

6. Contributed paper at the Optical Society of America Annual Meeting, "Electrooptic and piezoelectric measurements in photorefractive materials," Seattle, Washington, October 1986.

7. Contributed paper at the Optical Society of America Annual Meeting, "Controlling the frequency shift of a self-pumped phase conjugator," Seattle, Washington, October 1986.

8. Contributed paper at the Optical Society of America Annual Meeting, "All-optical measurement of the photovoltaic effect in barium titanate," Seattle, Washington, October 1986.

INFORMATION ELECTRONICS

ANALYSIS AND SYNTHESIS OF PARALLEL PROCESSING SYSTEMS

Dan I. Moldovan & G. Bekey
Research Unit IE2-1

For the period 1 January 1986 through 31 December 1986

Progress

In 1986 the research has focused on the following two main issues:

Parallelism analysis in rule-based systems. We developed techniques for reduction of search spaces in rule-based systems based on the study of rule inter-dependencies. Algorithms for allocation of rules to multiprocessors were studied. Simulations of parallel executions of rule-based systems were performed. These results can be directly applied for speeding up the execution of expert systems. The following papers from the 1986 document our results: Publications 2 and 5; and Presentations 2, 4, 5, 6, and 7.

Mapping of algorithms into array processors. This is a continuation of our previous work in the area of mapping algorithms into parallel computers. Specifically we investigated the partitioning of algorithms, algorithms whose data communication is described by permutations and tradeoffs between design parameters of array processors. These results were presented in the following 1986 publications 1, 3, 4, and 6; and presentations 1 and 3.

List of Publications

1. D.I. Moldovan and J.A.B. Fortes, "Partitioning of Algorithms for Fixed Size VLSI Architectures," IEEE transactions on Computers, **C-35,** No.1, (1986).

2. V. Dixit and D. I. Moldovan, "SNAP and its Applications to Image Understanding, " accepted to IEEE TRANS. on PAMI, to be published Jan. 1987.

3. D. I. Moldovan, "ADVIS: A Software Package for the Design of Systolic Arrays," accepted to IEEE transactions on Computer-Aided Design of Integrated Circuits and Systems, to be published Jan. 1987.

4. D.I. Moldovan and T. C. Lin, "Tradeoffs in Mapping Algorithms into Array Processors, " submitted to IEEE Transactions on Computers, in May 1985, revised May 1986

5. D.I. Moldovan, "Parallel Processing of Production Systems," submitted to IEEE trans. on systems, Man and Cybernetics, in 1986.

6. T. C. Lin and Dan I. Moldovan, "Mapping of Algorithm Permutation into Mesh-Connected SIMD Computers,: submitted to IEEE Transactions on Computers, in 1986.

List of Presentations

1. Dan I. Moldovan, "A systolic Array for Optimal Binary Search Tree Algorithm, "Proc. 20th Hawaii International Conference on Systems Sciences, Jan. 1987, Invited paper.

2. Dan I. Moldovan, et al, "Parallelism Analysis in Rule-Based Systems Using Graph Grammar Theory," Proc. International Workshop on Graph Grammers, Dec. 1986.

3. T. C. Lin and D. I. Moldovan, "M^2-Mesh: An Augmented Mesh Architecture," Proc. 1986 International Conference on Parallel Processing, Aug. 1986.

4. Yu-Wen Tung and Dan I Moldovan, "Detection of AND - Parallelism in Logic Programs," Proc 1986 International Conference on Parallel Processing, Aug. 1986.

5. D. I. Moldovan and C.I. Wu, " Parallel Processing of a Knowledge-Based Vision System," Proc. 1986 Fall Joint Computer Conference, Nov. 1986, Dallas, Invited paper.

6. Dan I. Moldovan, "A Comparison Between Parallel Processing of Numeric and Symbolic Algorithms," International Workshop on Parallel Algorithms and Architectures, Marseille, France, April 1986.

7. Dan I. Moldovan, "A Model for Parallel Processing of Production Systems," invited paper for 1986 International Conference on Systems, Man and Cybernetics, Atlanta, Ga., Oct. 1986.

BASIC RESEARCH IN C^3 DISTRIBUTED DATABASES

Victor O.K. Li
Research Unit IE2-2

For the period:1 January 1986 through 31 December 1986

Progress

In the past year, we have focused on three areas of basic research in distributed databases, namely, performance modeling of concurrency control algorithms, query processing, and termination protocols. In Pub. 1 and Pres. 3, we have developed two performance models for timestamp-ordering algorithms. We believe our work represent the first successful attempt to model timestamp-ordering algorithms without resorting to simulations. The model for locking algorithms that we have developed (Pub. 5) allows one to include the effect of deadlocks. The Precedence-Assignment model (Pres. 1) is a unified model of most existing concurrency control algorithms. In the area of query processing, we have developed the relation-partitioning approach to query processing (Pres. 4), and a query processing algorithm applicable to distributed databases managed on a local area network (Pub. 3 and 4). We have also developed termination protocols in distributed databases managed on networks with unreliable components (Pres 2 and Pub 6).

Our paper describing the Event-Based Reliability Model (EBRM) for communications networks has been published. This paper has generated much interest in the research community, and we have received a number of requests for reprints. EBRM allows one to model and evaluate the reliability/availability of a network in which the components have dependent failures. Details of this model are given in Pub. 2.

List of Publications

1. Li, V.O.K., "Performance models of timestamp-ordering mynchronizationmlgorithms in distributed databases." To appear in the IEEE Trans. on Computers.

2. Lam, Y.F. and Li, V.O.K., "Reliability modeling and analysis of communication networks with dependent failures." IEEE Trans. on Communications, **COM-34**, No. 1, 82 (1986).

3. Systems on a local area network." Submitted to IEEE Trans. on Software Engineering.

4. Chen, S.J. and Li, V.O.K., "An Efficient Algorithm for Finding a Minimum-Weight Vertex Cover for a Bipartite Graph." Submitted to Operations Research.

5. Shyu, S.C. and Li, V.O.K., "Performance analysis of static locking in distributed database systems." Submitted to ACM SIGMETRICS.

6. Huang, C.L. and Li, V.O.K., "A High-Availability Quorum-Based Termination Protocol for Distributed Database Systems." Submitted to ACM SIGMOD.

List of Presentations

1. Wang, C.P. and Li, V.O.K., "The precedence-assignment model for distributed database concurrency control algorithms," Proc. ACM Symposium on Principles of Database Systems, San Diego, California, March 1987.

2. Huang, C.L. and Li, V.O.K., "Termination protocols for simple network partitioning in distributed database systems," Proc. IEEE Data Engineering Conference, Culver City, California, February 1987.

3. Wang, C.P. and Li, V.O.K., "Queueing analysis of the conservative timestamp-ordering concurrency control algorithm," Proc. International Computer Symposium, Tainan, Taiwan, December, 1986.

4. Wang, C.P. and Li, V.O.K., "The relation-partitioning approach to query processing in distributed databases," Proc. IEEE Data Engineering Conference, Los Angeles, California, February 1986, pp. 21-28.

IMAGE TEXTURE ANALYSIS AND RESTORATION USING NONSTATIONARY MODELS

A.A. Sawchuk
Research Unit IE2-3

For the period:1 January 1986 through 31 December 1986

Progress

Work on multiple-resolution texture segmentation has continued with the goal of determining the best techniques for utilizing spatial information to avoid the effects of the nonstationary statistics of the classification features. The effort concentrates on both the low-level (texture feature extraction and smoothing of feature estimates) and at the high level (segmentation algorithms incorporating spatial information).

At the low level, have concentrated on improved methods of generating useful spatial information to use in the final classification step. We are examining techniques of low-level texture feature smoothing, such as the use of adaptive smoothing filters

(previously applied only to gray scale intensity values) to avoid feature mixing at region boundaries.

At higher levels, we have been testing a variety of techniques for combining information obtained at several different scales of spatial resolution in order to find the optimum final texture classification.

Several different methods for performing the final hierarchical classification have been tested. The methods vary in complexity and effectiveness and the current goal is to select the method that performs well at an acceptable computational speed. One technique uses the coherence or compatibility of a pixel with its local neighbors to refine the segmentation process, especially at region boundaries. Iterative relaxation algorithms such as the Rosenfeld-Hummel-Zucker and Peleg methods are being tried.

Most experimental work to date has concentrated on the segmentation of test images consisting of a mosaic of textures arranged as rectangles with vertical and horizontal boundaries. Our current work is aimed at examining the robustness of these methods by testing them on more general types of texture mosaic patterns having rotated rectangular regions and regions with non-rectangular curved boundaries.

List of Publications

1. D.T. Kuan, A.A. Sawchuk, T.C. Strand, and P. Chavel, "Adaptive Noise Smoothing Filter for Images with Signal-Dependent Noise," IEEE Trans. Patt. Analysis and Machine Intelligence, **PAMI-7**, 165 , (1985).

2. S.-S. Jiang and A.A. Sawchuk, "Noise Updating Repeated Wiener Filter and Other Adaptive Noise Smoothing Filters Using Local Image Statistics", Applied Optics, **25**, 2326, (15 July 1986).

3. S.-S. Jiang and A.A. Sawchuk, "Speckle Noise Suppression Using a Noise Updating Repeated Wiener Filter", submitted to Applied Optics.

4. S.-S. Jiang and A.A. Sawchuk, "Image Restoration Using a Least Square Pseudoinverse Filter and a Noise Updating Repeated Wiener Filter", submitted to Applied Optics.

5. D.T. Kuan, A.A. Sawchuk, T.C. Strand, and P. Chavel, "Adaptive Restoration of Images with Speckle," submitted to IEEE Transactions on Acoustics, Speech and Signal Processing.

List of Presentations

1. B.G. Ghaffary, E.M. Bassett, and A.A. Sawchuk, "A Study of Texture Segmentation," Proceedings Society of Photo-Optical Instrumentation Engineers Technical Symposium-Applications of Digital Image Processing IX, SPIE Vol. 976, San Diego, August 1986,

2. A. Weber, R. Chellappa, and A.A. Sawchuk, "Educational Laboratory for Image Processing/Analysis Using Personal Computers," Proc. NECC '86 7th National Educational Computing Conference, San Diego, June 4-6, 1986.

REDUCED MODELING THROUGH OPTIMAL PHASE MATCHING

E. A. Jonckheere and L. Silverman
Research Unit IE2-4

For the period: 1 January 1986 through 31 December 1986

Progress

LONG TERM OBJECTIVE AND MOTIVATION

The long term objective of this research is to derive either a transfer function model

$$y(s) = \frac{\beta_n s^n + \ldots + \beta_0}{\alpha_n s^n + \ldots + \alpha_0} u(s)$$

or a state space model

$$\frac{dx}{dt} = Ax + Bu, y = Cx + Du$$

that interpolates an *experimental* frequency response data $\{(u(j\omega), y(j\omega))\}$.

The problem formulation grew out of the Investigator's joint work with Livermore Lab, a research pertaining to the control of SDI laser weapons. The finite elements or partial differential equation modeling of very large space flexible structures is most likely to overwhelm the control designer with, say, 10,000-20,000 vibration modes. The on-board laser beam pointing control system could not possibly take into consideration all structural vibration modes. Besides this curse of dimensionality, the higher eigenfrequencies could be as much as 300%-500% in error and the modeling of

structural damping, hysteresis, etc. will be extremely difficult. The approach taken here radically departs from modeling from "first principles." Here, we derive a model, of acceptable size n, that matches the actuator-sensor relationship *as it is revealed through on line experiments*. The experimental data is chosen to be the gain and phase frequency response data, because sine wave excitation is easy to reproduce experimentally and because phase and gain are most relevant to feedback control.

An ideal test-bed appears to be the piezoelectric beam of the Aerospace Corporation (Terry Brennan). It is a flexible beam coated with a piezoelectric material that acts both as actuating and sensing device. The rate sensor and the force actuator are co-located; hence the transfer function is stable/minimum phase, and identification is possible from the phase data only. Both the actuator input and the sensor output are electrical, so that sine wave excitation is easy, as well as measurement of the phase shift between $u(j\omega)$ and $y(j\omega)$.

SPECIFIC RESULTS OF THIS YEAR

The key to the mathematical solution of the above formulated problem was found in the course of this JSEP work unit. Consider an experimental phase data.

$$\phi(j\omega_k) = \angle \frac{y(j\omega_k)}{u(j\omega_k)}$$

With this experimental phase data we construct exp(2j (wk)), map it to the z-transform domain, and an FFT yields the Laurent expansion

$$exp(2j\phi(\omega_k)) = \ldots + a_1 z + a_0 + a_{-1} z^{-1} + \ldots$$

Then we construct the *Hankel* matrix

$$H = \begin{vmatrix} a_{-1} & a_{-2} & \ldots \\ a\text{-}2 & \ldots & \\ \vdots & & \end{vmatrix}$$

The reduced order model (A,B,C,D) that matches the phase data is derived from the *singular value decomposition* of H. It should be stressed that these manipulations are *finite dimensional matrix operations* and no complex nonlinear programming is required as it is the case in parametric optimization.

The most relevant result obtained in the course of this year of research is the following bound on the error between the experimental phase data ϕ and the phase ϕ of the model of order n:

$$\forall \omega, |\phi(j\omega) - \phi(j\omega)| \leq \sin^{-1}(\sigma_{n+1} + \sigma_{n+2} + \ldots)$$

where $\sigma_1 > \sigma_2 > \ldots > 0$ are the *singular values* of the Hankel matrix. The salient feature is that the goodness of the model can be assessed *directly from the experimental data*, which is not the case for optimal parametric modeling through nonlinear programming.

List of Publications

1. E. A. Jonckheere and R. S. Li, "L^∞ error bound for phase matching approximation - the one step at a time Hankel norm model reduction version," to appear in International Journal of Control, 1987.

List of Presentations

1. E. A. Jonckheere and J. C. Juang, "Hankel and Toeplitz operators in linear quaohalic and H2O designs," NATO Conference, Groninge, the Netherlands, December, 1986.

RESEARCH IN COMPUTER VISIONS

Rama Chellappa
Research Unit IE2-5

For the period 1 January 1986 through 31 December 1986

Progress

The goal of this research unit is to develop model based algorithms for some computer vision problems. We have made significant progress over the last twelve months in developing algorithms for extracting edges from noisy images, and for extracting linear features from images of man made structures such as airports and buildings. The potential application of this research is in smart interpretation of aerial images.

Both these algorithms extend the edge detector developed during the first year of the project. This edge detector represents the pixels in the noise free image by using a space-variant correlated autoregressive (AR) random field model. Due to this assumption, the first and second directional derivatives are approximated as a function of

the model parameters and intensity values in a local 3 x 3 window. An edge is detected if the second derivative in the direction of the estimated maximum gradient is negatively sloped and if the first directional derivative and a local estimate of variance satisfy some constraints.

The linear feature extractor we have developed consists of tracing the edge points detected as mentioned above, linking and fitting with lines. The heuristics used in tracing and linking are specific to the characteristics of the the AR model based edge detector. The performance of the linear feature extractor is illustrated in Figure 1. Edge detection in noisy images is done by jointly estimating the parameters of the AR model and the intensity values in the local window mentioned above using a reduced update Kalman filter (RUKF). The overall algorithm is interleaved so that the information required for edge detection at (x_0,y_0) is computed by the RUKF centered at $(x_0 + 1,y_0 + 1)$.

List of Publications

1. Y. T. Zhou, R. Chellappa and V. Venkateswar, "Edge detection using zero crossing of directional derivative of a random field model", Intl. Conf. on Acoustics, Speech, and Signal Processing, Tokyo, Japan, April 1986. (Was presented by Chellappa at this meeting)

2. R. Chellappa,"Model based approaches for some low level computer vision problems", Invited paper, Conf. on AI and Advanced Technology, New port Beach, May 1986. (Was presented by Chellappa at this meeting)

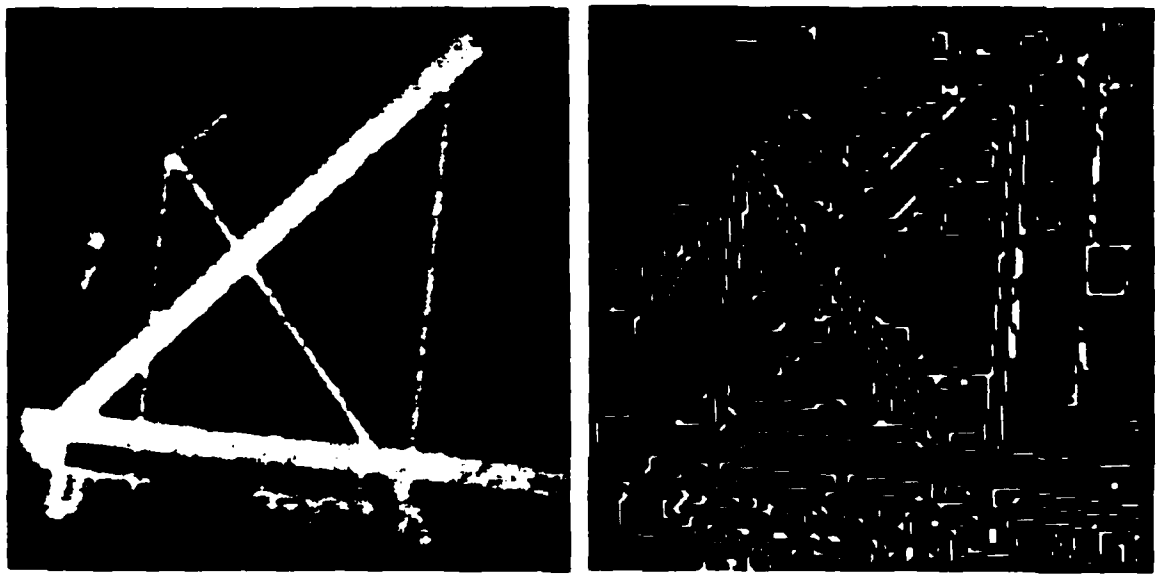
3. Y. T. Zhou, R. Chellappa and V. Venkateswar, "Edge detection using the directional derivatives of a space varying random field model", IEEE Conf. on Computer Vision and Pattern Recognition, Miami, Florida, June 1986. (Was presented by Chellappa at this meeting)

4. Y. T. Zhou, A. Rangarajan and R. Chellappa, "Simultaneous filter/detector for edge detection in noisy images", International Symposium on Information Theory, Ann Arbor, MI., Oct. 1986. (Was presented by Zhou at this meeting)

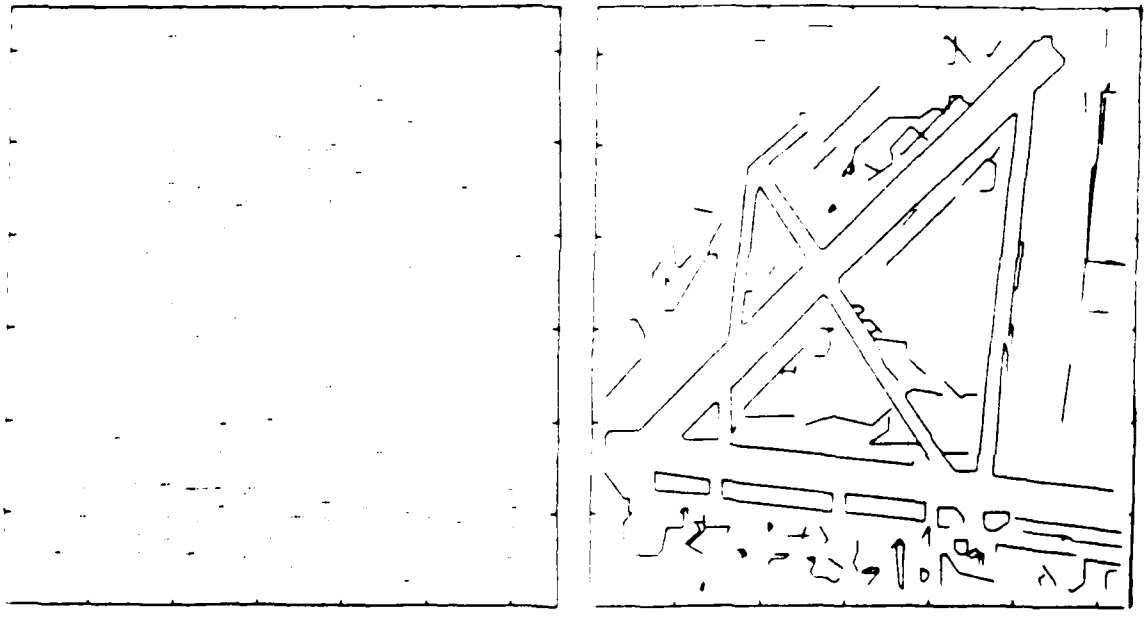
5. Y. T. Zhou and R. Chellappa, "Linear feature extraction based on an AR model ridge detector", to appear in Intl. Conf. on Acoustics, Speech, and Signal Processing, Dallas, TX, April, 1987. (Will be presented by Zhou at this meeting)

Research Unit IE2-5 Figure 1:

Linear segments of the airport image extracted using our method. (a) Original airport image. (b) Outputs of the AR model based edge detector. (c) Edge diagram indicating edge pixels as dots and (d) Linear segments.



(a) (b)



(c) (d)

END

4-87

DTIC